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AN ANALOG DELAY NETWORK FOR ADAPTIVE BEAMFORMING.(U)
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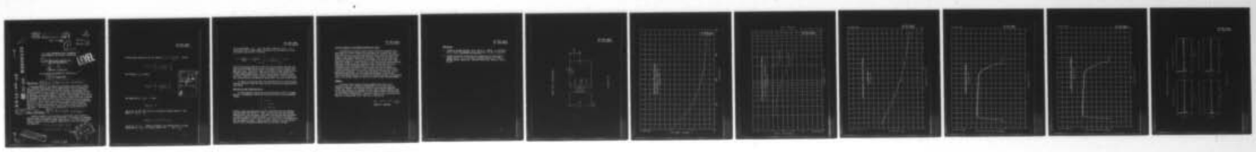

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U. S. NAVY UNDERWATER SOUND LABORATORY
FORT TRUMBULL, NEW LONDON, CONNECTICUT

AN ANALOG DELAY NETWORK FOR ADAPTIVE BEAMFORMING

by

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42 p.

Technical memo.

Introduction

Implementation of the adaptive beamforming algorithms of Widrow and Griffiths requires the use of tapped delay lines to synthesize transversal filters.[1,2] An all digital processor can provide ideal delays by means of shift registers, but the main disadvantage of such an approach is the large number of multiply-add operations which must be performed during each sampling interval. This problem can be solved by implementing a hybrid system in which the weight values are calculated digitally and then used to control the gains at taps on an analog delay line. Since rather large amounts of delay over broad bandwidths are often required, one could use conventional LC delay networks. However, it would be preferable to use circuits which consume much less space. The purpose of this memorandum is to describe such a network.

Circuit Description

Shown in Figure 1 is an all-pass network which can be used to provide delay over a rather large bandwidth. The network is sometimes used in control systems for phase equalization. To obtain the voltage transfer function, we use Laplace transforms to write the following two equations.

$$2n\,E_{in}(s) = I(s)\left[R + \frac{1}{Cs}\right]$$

$$n\,E_{in}(s) = R\,I(s) + E_{out}(s)$$

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Solving these equations for the quantity $H(s) = \dfrac{E_{out}(s)}{E_{in}(s)}$ gives:

$$H(s) = n\left[\frac{1 - sRC}{1 + sRC}\right]$$

Now letting $s = j\omega$ we have:

$$H(j\omega) = n\left[\frac{1 - j\omega RC}{1 + j\omega RC}\right]$$

The magnitude of $H(j\omega)$ is then:

$$|H(j\omega)| = n$$

and so we see that the circuit is indeed an all-pass network. The phase of $H(j\omega)$ is:

$$\phi(j\omega) = -2\tan^{-1}(\omega RC)$$

A plot of $\phi(j\omega)$ appears in Figure 2 and reveals that to a good approximation $\phi(j\omega)$ is a linear function of ω for $\omega < \frac{1}{RC}$.

If we approximate $\phi(j\omega)$ over its linear range by $\hat{\phi}(j\omega) = -\omega T$, then we can find an approximate expression for the amount of delay provided by the circuit. We have:

$$T = -\frac{d\hat{\phi}(j\omega)}{d\omega} \simeq \left. \frac{-d\phi(j\omega)}{d\omega} \right|_{\omega=0} = \left[\frac{2RC}{1 + (\omega RC)^2} \right]_{\omega=0} = 2RC$$

From the preceding expressions one can see two reasons why this network is more attractive as a delay unit than would be a simple low-pass RC filter. The first reason is that the all-pass characteristic prevents signal distortion. The second reason is the factor of 2 in the phase characteristic, which a single stage low-pass RC does not have. Thus for a given resistor and capacitor, the all-pass network provides twice the amount of delay that a low pass filter would.

It should be mentioned that the transformer used in the all-pass network can have a very low power rating, and hence can physically be very small.

<u>Measured Circuit Characteristics</u>

To experimentally determine the characteristics of the all-pass network, a breadboard version was built with the following parameter values

$$n = \frac{1}{2}$$

$$R = 10\ K\Omega$$

$$C = 6800\ pf.$$

Figure 3 shows the amplitude and phase characteristics as measured over the band from 200 Hz to 5 kHz. One can see that the all-pass characteristic was excellent. The phase function has been replotted in Figure 4 against linear frequency. Let us arbitrarily choose a band of interest to be 425 Hz to 2.4 kHz, since this is representative for some passive sonars. From the plot in Figure 4 one can see how nearly linear the measured phase function was over the band.

Circuit Response to Broadband Random Noise Input

To determine how the all-pass network affected broadband noise, the output of a Scott random noise generator was filtered into the band from 425 Hz to 2.4 kHz, and then used as an input to the network. Figure 5 shows the measured power spectral density of the input, and Figure 6 the spectral density of the output. One can see that they are nearly identical, as should be the case for a filter with a flat amplitude response. Shown in Figure 7 are the measured autocorrelation functions of the input and output processes, along with the cross-correlation function between the two. One can clearly see the excellent delay line action of the network from the fact that the cross-correlation function is just a shifted version of the two autocorrelation functions. In this case the amount of delay was 1/8 ms. The author apologizes for the unconventional manner in which the cross-correlation function is plotted for negative delays; unfortunately this is the output format for the device used to make the measurement.

Summary

An analog delay network has been examined and found to be attractive for use in adaptive beamforming. The circuit uses no inductive elements, and provides delays of the required magnitude. In the near future it is planned to join several stages together with the necessary buffering and gain controls (most likely to be provided by field effect transistors). Tests will then be run to determine the quality of transversal filter that can be synthesized.

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References:

1. "Adaptive Antenna Systems" by B. Widrow, P. Montey, L. Griffiths, and B. Goode, Proceedings of the IEEE, Vol. 55, No. 12, Dec 67.

2. "Signal Extraction Using Real-time Adaptation of Linear Multichannel Filter" by L. Griffiths, Technical Report No. 6788-1, Systems Theory Laboratory, Stanford University, Stanford, Calif., Feb 68.

All - Pass Network

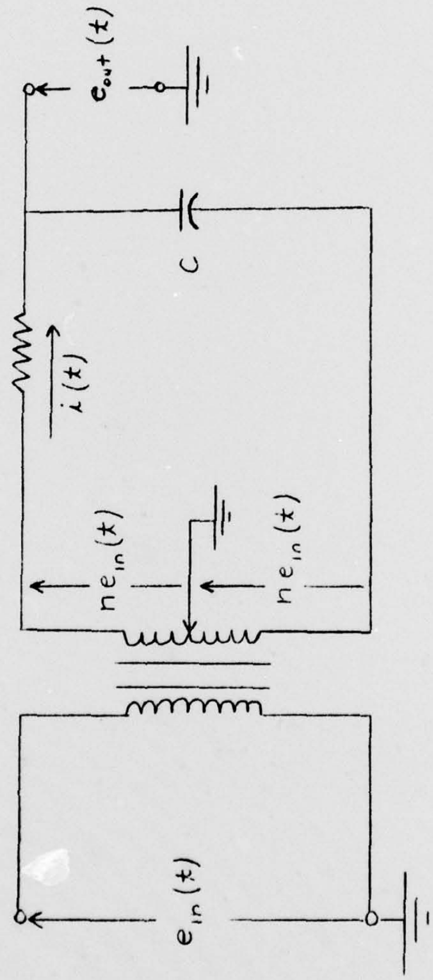
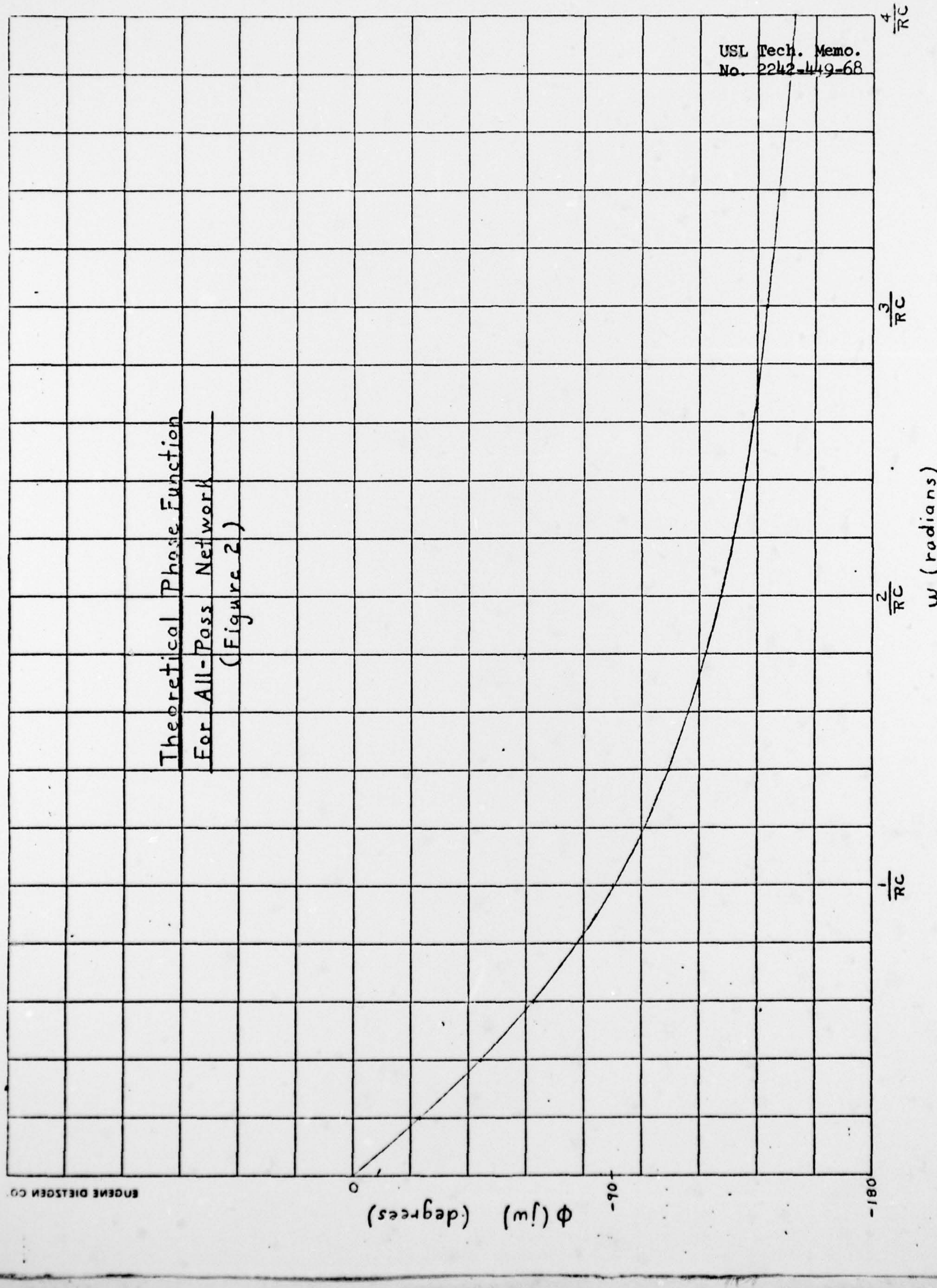


Figure 1



Theoretical Phase Function
For All-Pass Network
(Figure 2)

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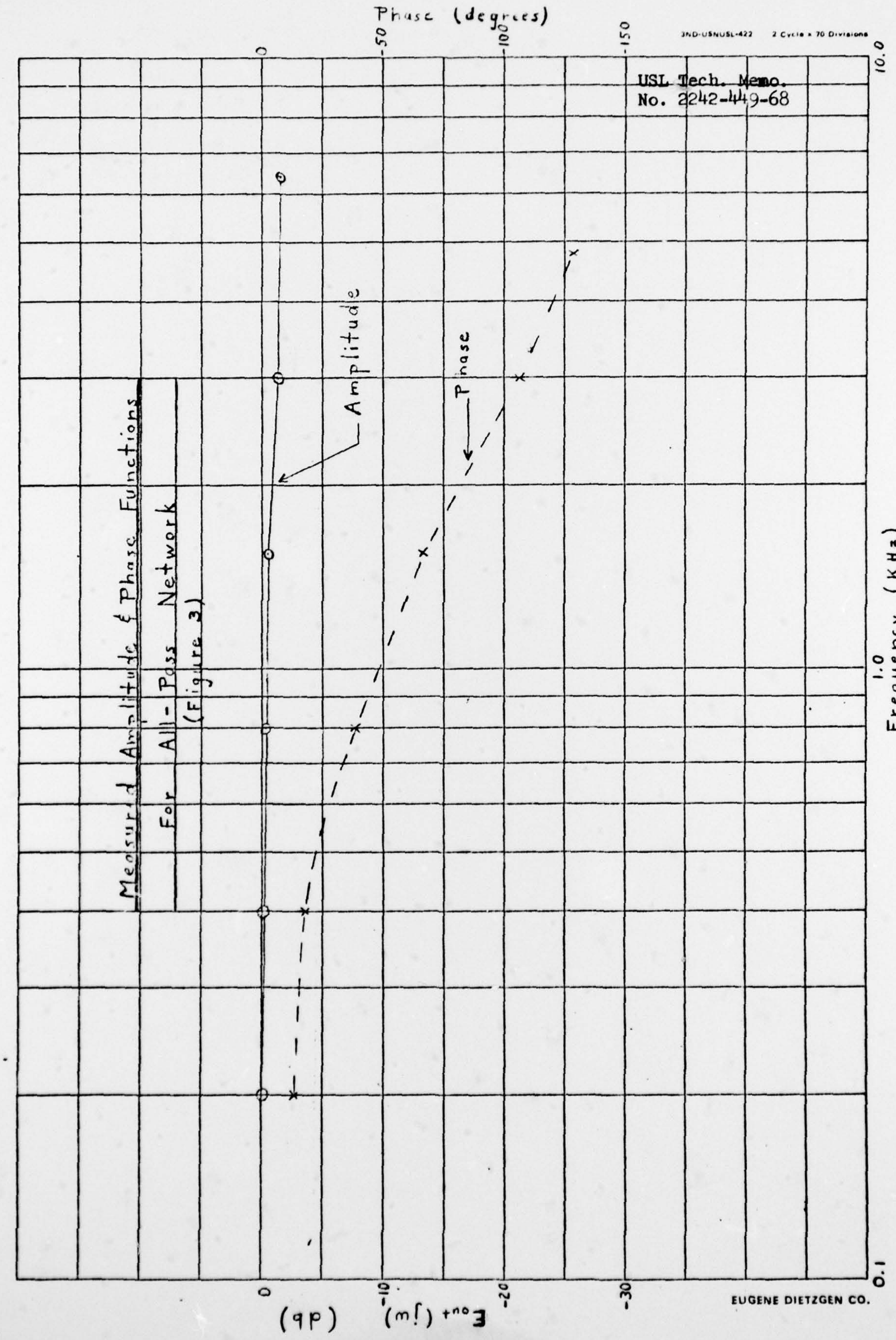
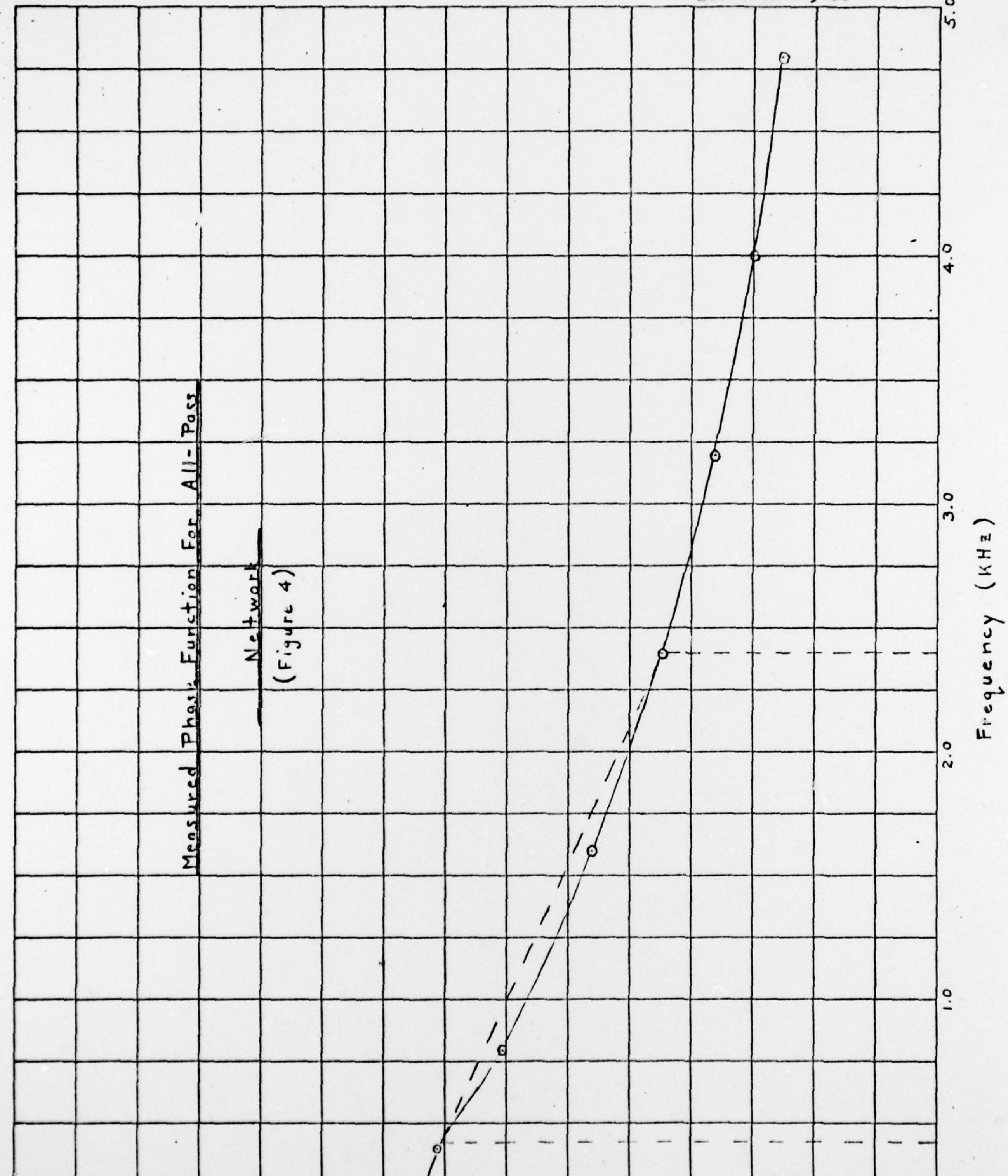
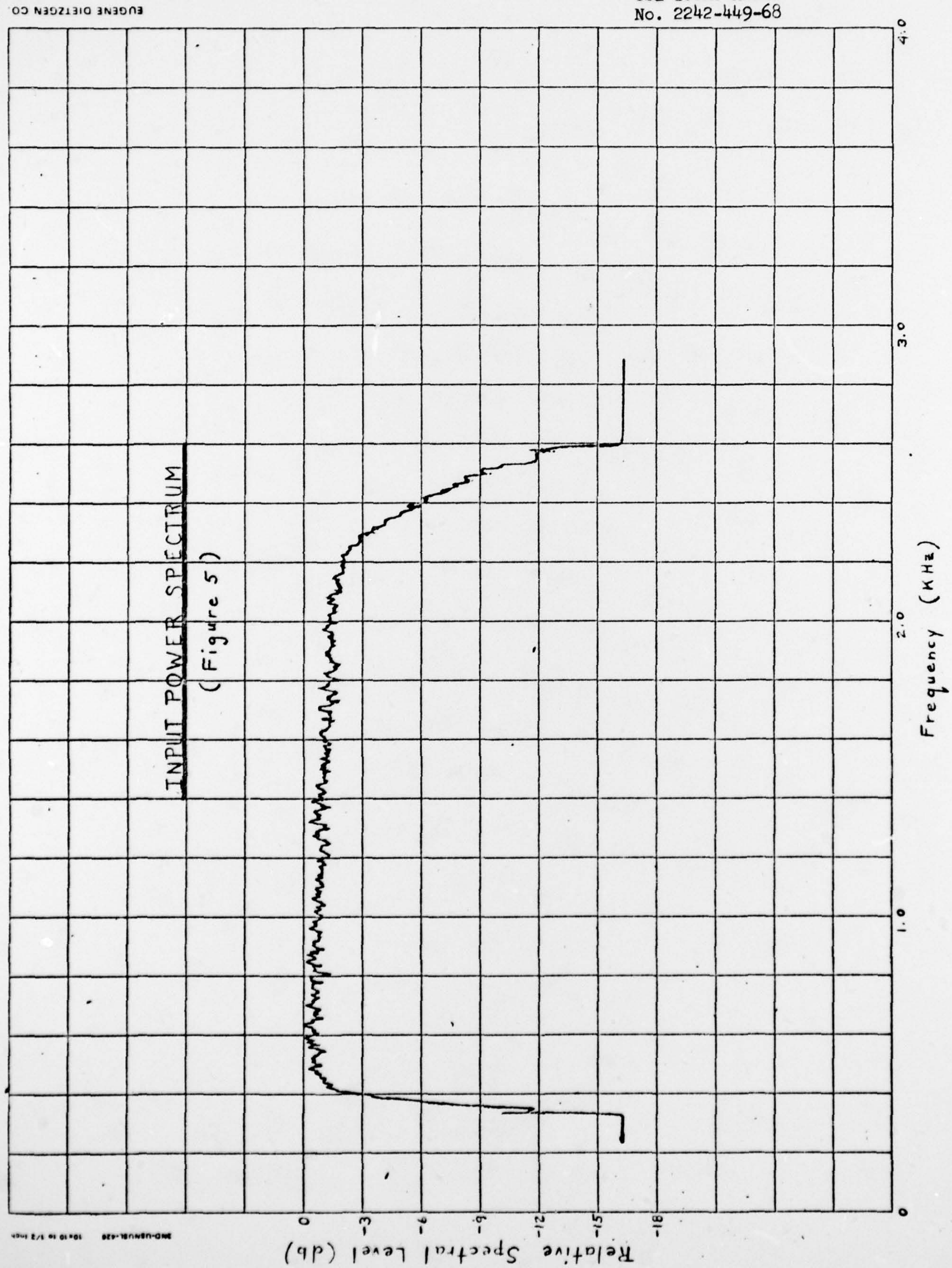


Measured Amplitude & Phase Functions
For All-Pass Network
(Figure 3)



Measured Phase Function For All-Pass Network

(Figure 4)


INPUT POWER SPECTRUM
(Figure 5)
Frequency (KHz)
0
1.0
2.0
3.0
4.0
Relative Spectral Level (db)
0
-3
-6
-9
-12
-15
-18
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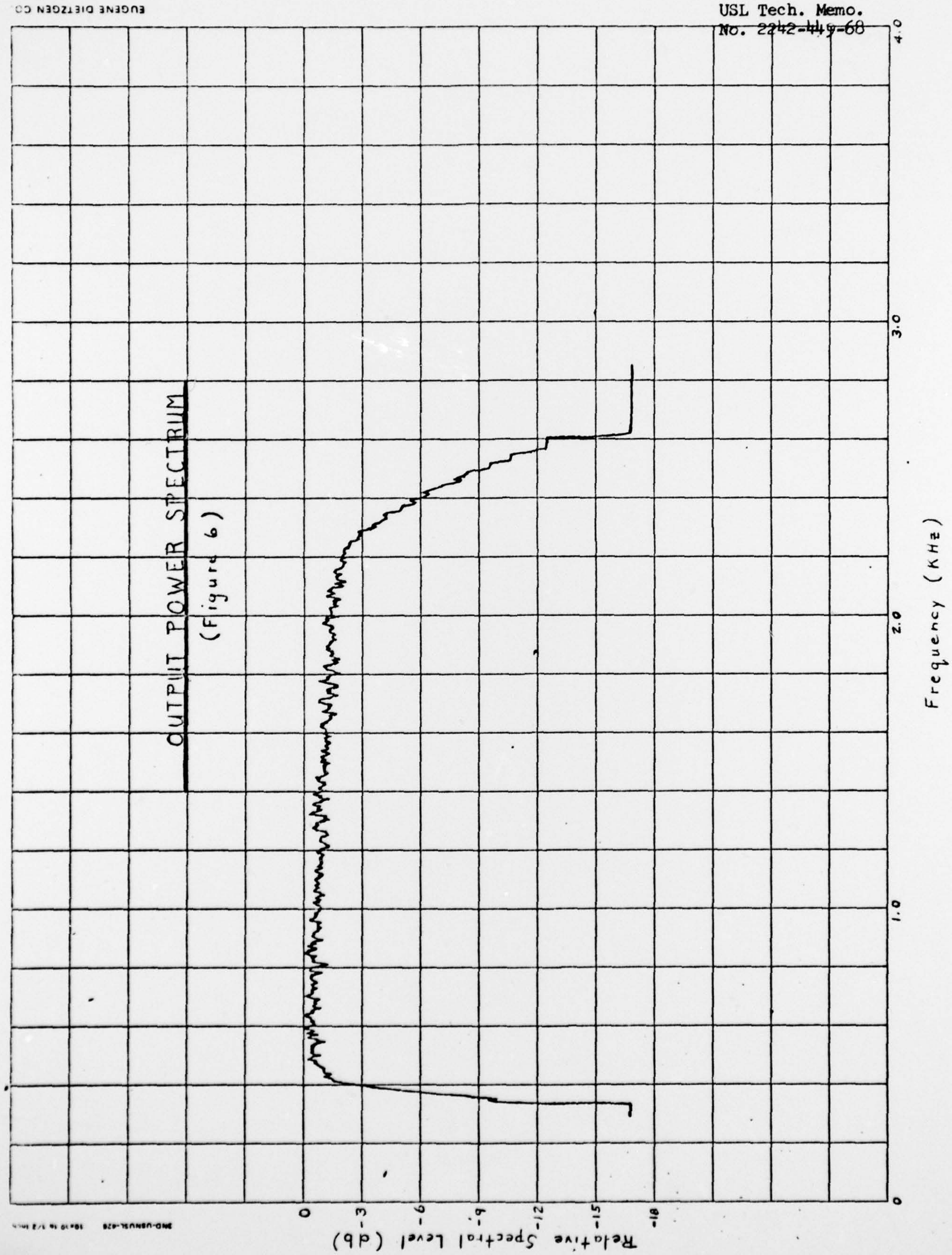
OUTPUT POWER SPECTRUM
(Figure 6)
Frequency (KHz)
0
1.0
2.0
3.0
4.0
Relative Spectral Level (db)
0
-3
-6
-9
-12
-15
-18
EUGENE DIETZGEN CO

Measured Correlation Functions

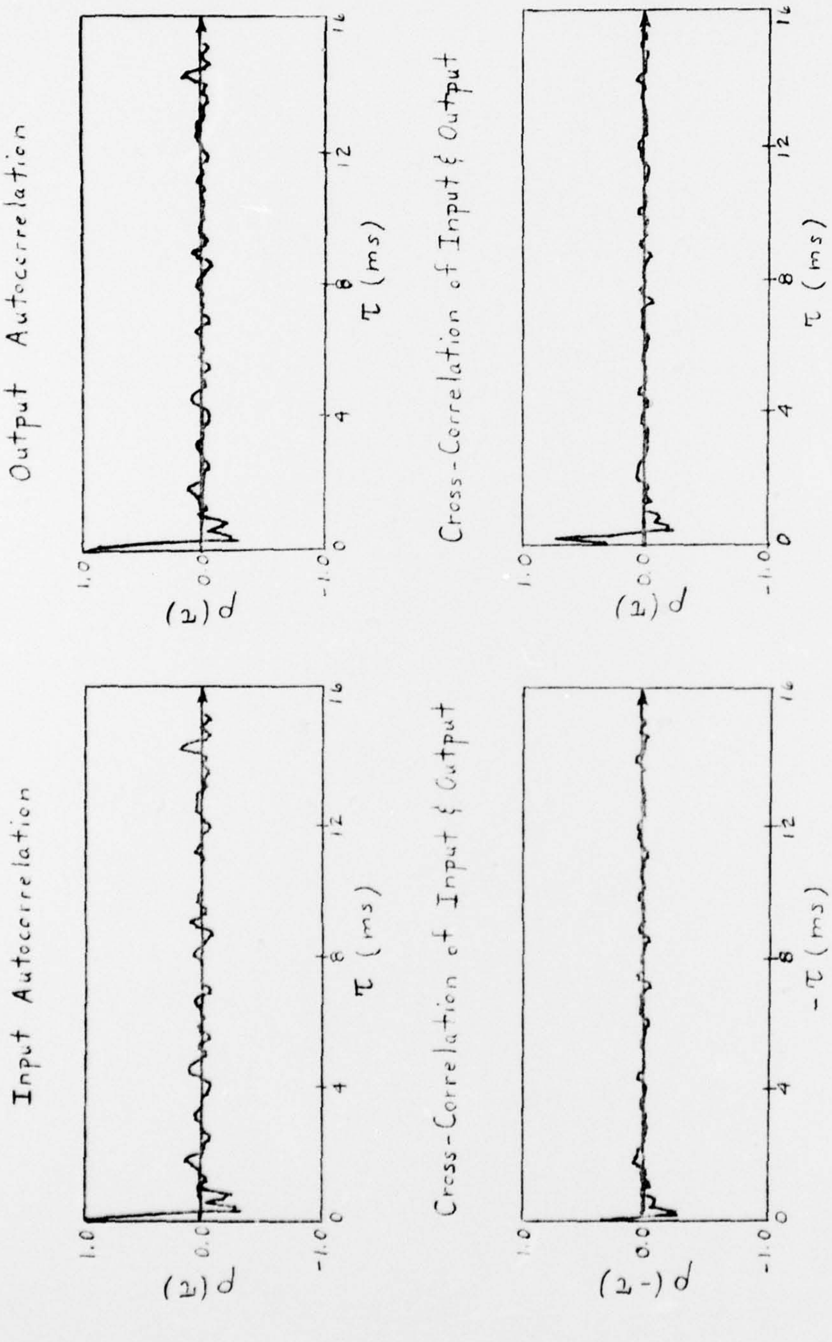

Figure 7